Impact of atmospheric ammonia on growth, C and N accumulation and photosynthesis of two maize cultivars with different N root supply

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ABSTRACT

Impact of enriched atmospheric NH_3 in combination with low and high N medium on growth, total C and N accumulation ($C_{tot}A$ and $N_{tot}A$) and photosynthetic characteristics of two maize cultivars i.e. SD19 (cult. 1) and NE5 (cult. 2) with low N and N high use efficiency, respectively, was investigated. Plants were exposed to 10 nl/L and 1000 nl/L NH_3 fumigation, respectively, for 30 days in open-top chambers (OTCs). Under exposure to the low N medium, increase of the atmospheric NH_3 concentration to 1000 nl/L from the ambient level significantly ($P < 0.05$) increased dry matter (DM) (by 18% in cult. 1 and 14% in cult. 2 respectively), $C_{tot}A$, $N_{tot}A$, net photosynthetic rate (P_n), stomatal conductance (G_s) and apparent quantum yield (AQY) but decreased intercellular CO_2 concentration (C_i) in both cultivars. These effects were more pronounced in cult. 1 as compared to those in cult. 2. In contrast, in the high N solution, enriched atmospheric NH_3 led to a decrease in DM, $C_{tot}A$, $N_{tot}A$, P_n, G_s and AQY but an increase in C_i of cult. 2 only. Dark respiration rate remained unaffected by enrichment of NH_3 in each treatment. Therefore, it is concluded that appropriately enriched atmospheric NH_3 can improve plant growth of maize by enhancing $C_{tot}A$, $N_{tot}A$, and photosynthesis in the low N medium, especially for low N use efficiency cultivars.

Keywords: atmospheric ammonia enrichment; dry matter; carbon accumulation; nitrogen accumulation; photosynthetic characteristic

Among the atmospheric N species, ammonia (NH_3) is not only an important atmospheric pollutant for semi-natural vegetation, but one of the key N sources for N-deficiency plants in atmosphere. Annual NH_3-N deposition in each of the 4 years 2003–2006 was estimated to increase from 3.0 ± 0.2 kg N/ha year in ambient air, with the NH_3 concentration at 0.5 m above the canopy of 0.7 μg/m^3, to 50–70 kg N/ha year where annual average air concentrations were 70–90 μg/m^3 and concentrations during fumigation were up to 1600 μg/m^3 (Cape et al. 2008). Factors contributing to this significant increase in atmosphere NH_3 concentration include: vicinity to location of significant NH_3 emissions, climatic conditions, and agriculture activities. The latter contributes to 50% of the global NH_3 emissions (Fangmeier et al. 1994). Maize *(Zea mays* L.) is a staple food

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crop in northern China. This region is usually subjected to increasing atmospheric NH_3 emission to 0.30–1.60 mg/m^3 from regular mean air NH_3 concentration of 0.01–0.20 mg/m^3 due to high rate application of NH_3 forming fertilizers (Li et al. 2004). Atmospheric NH_3 is deposited to soil and water, either by dry deposition of NH_3 or by dry and wet deposition of ammonium (NH_4^+) (Fangmeier et al. 1994). As a plant nutrient, plants can utilize atmospheric NH_3 to improve plant growth and/or production if the mole fraction of NH_3 in the atmosphere is greater than the mole fraction of gaseous NH_3 in the substomatal cavity. Foliar NH_3 uptake by the leaves of Italian ryegrass (*Lolium multiflorum*) at 0.52 mg/m^3 supplied 47.3% and 35.2% of total plant N at fertilization levels of 100 and 200 mg $^{15}NO_3^-$-N/kg dry soil, respectively (Fangmeier et al. 1994). It was found that atmospheric NH_3 input is closely correlated with the morphology and metabolism of crops (Bohme et al. 2003, Li et al. 2009).

Exposure of plants to enriched atmospheric NH_3 may result in a significant impact on plant growth, total C and N (C_{tot} and N_{tot}) accumulation as well as photosynthesis, whose responses were dependent on plant species, growth stages and N availability for root uptake (Van der Eerden et al. 1991,1992, Sommer et al. 1993, Tatsuro et al. 2001, Li et al. 2004,2009). Li et al. (2009) concluded that enriched atmospheric NH_3 concentration increased shoot dry matter of wheat (*Triticum aestivum* L.) in the low N treatment but reduced the plant biomass in the high N treatment. In most cases, exposure to NH_3 generally results in an increase of soluble proteins concentrations in spruce (*Picea abies*) trees, N_{tot} and chlorophyll concentrations of Scots pine needles as well as photosynthesis of *Pinus sylvestris*, poplar trees and Douglas fir and dark respiration rate (R_d) of *Populus euramericana* as long as the tissue is not injured (Van Hove et al. 1989, Van der Eerden et al. 1992, Van der Eerden and Pérez-Soba 1992). Castro et al. (2005) pointed out that atmospheric NH_3 up to 4 µl/L can be regarded as a nutrient for the fast growing of *B. oleracea*. The concentration at which NH_3 changes from being a nutrient to a toxin is not clear-cut, since NH_3 can still be metabolized when plant growth is already affected (Fangmeier et al. 1994).

However, above studies mainly focus on forest and grassland vegetation. Much less attention has been paid to the effects of atmospheric NH_3 in agro-ecosystems. Additionally, evaluation of responses of maize crop to varying concentration of atmospheric NH_3 are not fully investigated. Keeping in view the above facts, we hypothesize that higher constitutive accumulation of C_{tot} and N_{tot} and photosynthesis induced by enriched atmospheric NH_3 may provide a mechanism of the improvement of plant growth of different maize cultivars under two levels of N in solution medium. Therefore, the objective of this study was to examine the growth response and accumulation of C_{tot} and N_{tot} as well as photosynthetic characteristic parameters of two maize cultivars, with different N use efficiency of plant, exposed to two levels of NH_3 concentration and N root supply in solution medium for 30 days.

MATERIALS AND METHODS

Plant material and experimental design. Solution culture experiments were conducted at Institute of Soil and Water Conservation, Chinese Academy of Sciences (Yangling, China). Two maize (*Zea mays* L.) cultivars i.e. SD19 (cult. 1) and NE5 (cult. 2) with low N and high N use efficiency, respectively, were supplied for the present experiments.

The open-top chambers (OTCs) used in the experiments (Figure 1) are containers described by Paul and Bert (1993), initially designed for exposing plants to elevated CO_2 concentrations under close to natural conditions, with a square 1.2 × 1.2 m base and 1.5 m tall perpendicular glass walls topped by glass quadrilaterals inclined towards the centre in an iron frame (total volume circa 3 m^3). The chambers were each equipped with a fan and an air control system, which included a steel cylinder (inner diameter 600 mm, total length 1800 mm) containing 95% NH_3. The NH_3 was fed from the bottom into the OTCs through a YQA-441 NH_3 decrement gauge with a pressure range of 0–4 MPa (Shanghai Shuangying Boat Decompressor Manufacture Co., Ltd., Shanghai, China) and Φ8 constant pressure oxygen pipes. The NH_3 flux was measured using an LZB-2 flux meter with anti-corrosion glass rotameter (measuring range 6–60 ml/min, rated working pressure ≤ 1 MPa) (Changzhou Shuangfa Thermal Instrument Co., Ltd., Changzhou, China). In addition, air was fed from the bottom of the OTCs using a ZB-0.10/8 air compressor (air displacement 0.1 m^3/min, rated air pressure 0.8 MPa) and Φ8 constant pressure oxygen pipes (Shanghai Luodi Air Compressor Co., Ltd., Shanghai, China). The air flux was maintained at 1.7 L/min, as measured by an LZB-2 flux meter

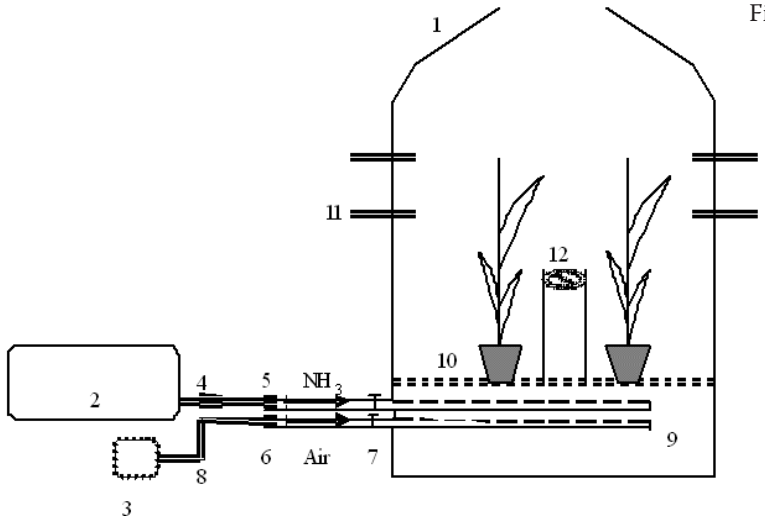

Figure 1. Open-top chamber (OTC) device

1 open-top chambers (OTCs)
2 steel tank with liquid NH_3
3 air compressor
4 NH_3 reductor
5 NH_3-flow meter
6 air-flow meter
7 piston
8 oxygen pipe
9 porous tubes
10 porous board
11 NH_3 test tube
12 small ventilator

with an anti-corrosion glass rotameter (measuring range 0.25–2.5 m^3/h, rated working pressure ≤ 1 MPa) (Changzhou Shuangfa Thermal Instrument Co., Ltd., Changzhou, China).

The temperature, humidity and NH_3 concentration inside each chamber were regulated by passing air (heated and moistened as appropriate) and NH_3 through porous pipes at the bottom of the container, while the fan (providing air speed of less than 0.5 m/s) was used to maintain close to uniform distribution of NH_3 and reduced temperature (if necessary) in the chamber. The temperature in the chambers was monitored to verify that the temperature was the same in the chamber before and after NH_3 was supplied, and thus that the effects of varying the NH_3 concentration on the growth parameters or C and N metabolism of plants were not confounded by variations in temperature.

The NH_3 concentration in each chamber was measured four times per day (at 8:00, 11:00, 14:00 and 17:00 h) by a GTL-C indoor air detector equipped with a pH618 test pen (NH_3 testing precision, ± 0.01 mg/m^3) (Shanghai Minyi Electron Co., Ltd., Shanghai, China) mounted on a tripod placed in the centre of the chamber before the gas was supplied. On each sampling occasion, 5 ml of NH_3 test reagent was extracted by an injector and injected into a glass bottle for sampling. The glass bottle was immediately plugged and connected to the instrument. During the tests, the flux was adjusted to 2 L/min and the exhaust time was controlled by the auto-timing device. When the sampling time was complete, the glass bottle was removed, unplugged, the reagent in the glass bottle was poured into the test cup and the test pen was inserted into the cup to measure the NH_3 concentration. Throughout the entire growth period, from 8:00–18:00 h every day, the NH_3 concentration in the OTCs used for the background, ambient (control) and elevated NH_3 treatments were maintained precisely at 10 nl/L and 1000 nl/L, respectively, by continuously supplying NH_3 and air at appropriate ratios.

Plant growth. Seeds of two maize cultivars were surface-sterilized in 10% H_2O_2 solution for 15 min. After rinsing in distilled water, seeds were imbibed for 12 h and then sown in porcelain trays containing quartz sand. Seeds were germinated in the dark under 23°C covering with clean wet filter papers. When the root grew to the length of 2–4 cm, the seedling was transferred and fixed in the holes of styrofoam boards by using absorbent cotton in deionized water in plastic trays in the growth chamber under the conditions with 25/18°C of average day/night temperature, 60–70% relative humidity, and 350 μmol/m^2/s light intensity and 16/8 h of light/dark regime. The solution was replaced once a day and aerated continuously.

PVC (polyvinyl chloride) pots with a volume of 3534 cm^3 (inner diameter 15 cm, height 20 cm) containing 3.5 L nutrient solution were used for plant growth. Ammonia fumigation and N treatments were initially proceeded on the 3rd day after the seedling transferred into OTCs at their three-leaf stage. The experimental design contained three factors which were NH_3 atmospheric concentration (at two levels: 10 nl/L, air background concentration and 1000 nl/L, high NH_3 concentration), N rate in medium (at two levels: 1/3 and 1/9 N concentration of complete nutrition solution i.e. 5.00 and 1.67 mmol/L nitrate) and maize cultivar (the two cultivars mentioned above), respectively, in a complete factorial design experiment with eight

treatments, and five replications per treatment. The 40 pots (one plant per pot) were randomly placed in four OTCs, and in order to reduce the experimental error the pots were exchanged in the four OTCs every 7 days. The low and high N rate in medium were served by 1/9 and 1/3 strength of the complete Hoagland nutrient solution, respectively. Desired N concentrations were maintained by irrigating sufficiently with new solution. The nutrient solution was amended with higher alcohol to make emulsion in order to restrain NH_3 exchange between two phase of gas and liquid. The pH of solution was adjusted to 6.2 (± 0.1). The top of pot was placed on a board with small holes for plants fixation, and the space between plants and holes were sealed with wax. The solution was aerated without NH_3 twelve hours a day. The plants of two maize cultivars were maintained for 30-day growth period under each treatment. The whole experiment was carried out twice independently under the same environmental conditions. Data presented here are means of five replicates of the two experiments (n = 10).

Measurements of dry matter and concentrations of total C and total N. Shoots of five plants in five pots of representing each cultivar and each of the treatments were collected from each chamber on the 30th day of N and NH_3 fumigation treatments (from 11:00 to 13:00 h), respectively. The samples were cleaned with distilled water, and were dried in a forced-ventilation oven at 65°C until constant dry weight. The dried samples were ground to pass a 1 mm screen for total C (C_{tot}) and total N (N_{tot}) assay. Concentrations of C_{tot} and N_{tot} were measured by potassium dichromate ($K_2Cr_2O_7$) volume method and the Kjeldahl method using an automatic N analyzer (Gerhardt Vapodest 5), respectively. Their total C and N accumulation ($C_{tot}A$ and $N_{tot}A$) based on the aboveground dry matter were calculated by multiplying their C and N content and dry matter, respectively.

Determination of photosynthetic parameters. The second completely developed leaf from the top of sample plant on the 30th day of NH_3 fumigation were measured from 9:00 to 11:00 h, respectively, using LI-6400 portable photosynthesis system (LI-COR Inc., Lincoln, NE, USA). The two leaves of one plant were determined and this was repeated in three replicates. The determination covered net photosynthetic rate (P_n, μmol $CO_2/m^2/s$), intercele lular CO_2 concentration (C_i, μmol/mol), stomatal conductance (G_s, mol/m^2/s) under the conditions of photosynthetically active radiation (PAR) of 1200 μmol/m^2/s and ambient CO_2 concentration of 360 μmol/mol. Apparent quantum yield (AQY, mol CO_2/mol) and dark respiration rate (R_d, μmol $CO_2/m^2/s$) were computed referring to the index model (1) of light response of maize under the setting PAR values of 2000, 1600, 1400, 1200, 1000, 800, 600, 400, 200, 150, 100, 50 and 0 μmol/m^2/s in turn and ambient CO_2 concentration of 360 μmol/mol condition (Guo et al. 2005).

$$P_n = P_{max} \left(1 - e^{-\frac{AQY\ PAR}{P_{max}}}\right) - |R_d| \quad (1)$$

Where: P_n represents leaf net photosynthetic rate under different PAR, and P_{max} indicates maximum net photosynthetic rate (μmol $CO_2/m^2/s$).

Data statistical analysis. All were subjected to the analysis of variance (ANOVA) with the SAS software package. Appropriate standard errors of the means (S.E.) were calculated for presentation with table and bar diagram. The significance of the treatment effect was determined using the *F*-test, and to determine the significance of the means, least significant differences (*LSD*) were estimated at 5% probability level, and Duncan's multiple range test was used for comparing treatments within two or three factors combinations.

RESULTS AND DISCUSSION

Plant growth. Plants can absorb moderate atmospheric NH_3 as source of N, and can thus positively benefit in term of plant growth and biomass production. Atmospheric NH_3 can enter the leaves of higher plants almost exclusively through the stomata and is dissolved in the water film of the mesophyll cells to form NH_4^+ as long as the ambient NH_3 concentrations exceed the mesophyll concentration (compensation point) (Fangmeier et al. 1994). Since NH_3 uptake by leaves occurred directly following stomatal conductance, the plant response to atmospheric NH_3 is dependent on environment factors, including crop cultivar and soil moisture availability (Rogers and Aneja 1980), internal CO_2 and NH_3 concentration, and plant water and fertilizer availability (Tatsuro et al. 2001). At the ambient NH_3 concentrations, its uptake by stem may have limited role in N-nutrition of higher plants. Enhanced growth was observed in many experiments within a reasonable range NH_3 concentrations, not approaching toxic level (Fangmeier et al. 1994). Enriched NH_3 concentrations can contribute to N-nutrition of plants, as was shown by Faller (1972) and Li et al. (2009).

Table 1. *F*-values of the effects of NH_3 level (NH_3), cultivar (Cv), N level (N) and their interactions on dry matter production (DM), total C accumulation ($C_{tot}A$) and total N accumulation ($N_{tot}A$)

Variation (g/plant)	N	Cv	NH_3	N × Cv	NH_3 × N	Cv × NH_3	N × Cv × NH_3
DM	176.55***	138.78***	0.97	22.46***	55.94***	2.70	0.40
$C_{tot}A$	4478.17***	2701.51***	78.84***	396.97***	388.39***	12.01**	22.70***
$N_{tot}A$	7718.18***	109.58***	1088.65***	292.19***	72.12***	78.82***	93.57***

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$

The current study supports the above conclusion as is evident from the positive effects of enriched atmospheric NH_3 concentration on plant growth in the low N (LN) solution. Fumigation of 1000 nl/L NH_3 greaterly increased DM production in SD19 (cult. 1) with low N use efficiency (NUE) (by 18%) than that in NE5 (cult. 2) with high NUE (by 14%) above the ambient concentration, which better counteract the negative effect of LN supply on shoot DM (Figure 1). Moreover, the single factor of N level and cultivar together with the interactions of N level and cultivar or NH_3 level had significant effects on DM production only (Table 1). Nitrate-deprived plants and low N use efficient cultivar can benefit from the atmospheric N source, since shoot biomass production recovered from nitrate deprivation (Castro et al. 2005). Atmospheric NH_3 at a concentration of 4 μmo1/L was therefore able to replace nitrate as nutrient to a considerable extent. This is in agreement with previous findings (Castro et al. 2005) and theoretical calculations on the possible contribution of NH_3 to the N budget of plants (Clement et al. 1997). In the high N (HN) solution, however, enriched atmospheric NH_3 reduced the DM production of cult. 2 (by 16%) with high NUE and non-significant effects of enriched atmospheric NH_3 on DM were found in cult. 1 with low NUE ($P > 0.05$) (Figure 2). Thereby, NH_3 assimilation under enriched atmospheric NH_3 under LN medium can improve plant growth. The canopy will respond to elevated atmospheric NH_3 concentration first, especially for the cultivar with low NUE in most natural environment with N limitation for plant biomass production (Fangmeier et al. 1994).

Accumulation of total C and total N ($C_{tot}A$ and $N_{tot}A$). The absorption and utilization of NH_3 supplied to the plants was evaluated by calculating $C_{tot}A$ and $N_{tot}A$, respectively. Ammonia (NH_3) uptake may cause an autocatalytic increase of additional NH_3 flux into the leaves by inducing stomatal opening via the internal CO_2 level (Van der Eerden et al. 1992). Long-term exposure of plants to moderate atmospheric NH_3 concentration may stimulate increased C and N assimilation in plant, which affects the internal C and N status of the plant (Castro et al. 2005). In *Calluna vulgaris* (heather) and *Deschampsia flexuosa* (hair-grass), the N content increased four-fold after exposure to 0.1 mg/m^3 NH_3 for 38 weeks. Varied increases of $N_{tot}A$ induced by enriched atmospheric NH_3 were found in other plants such as conifers, tomato *(Lycopersicon esculentum*), *Arnica montana* L. and *Viola canina* L. (Van der Eerden et al. 1991, 1992, Dueck and Elderson 1992, Clement et al. 1997, Li et al. 2009). Our study showed that enriched atmospheric NH_3 concentration increased $C_{tot}A$ and $N_{tot}A$ in both cultivars in the LN solution, relative to counterparts exposed to the ambient concentration. The above increases in biomass $C_{tot}A$ and $N_{tot}A$ were greater for cult. 1 (by 16% and 38%, respectively) than that for cult. 2 (by 12% and 32%, respectively). In contrast, in the

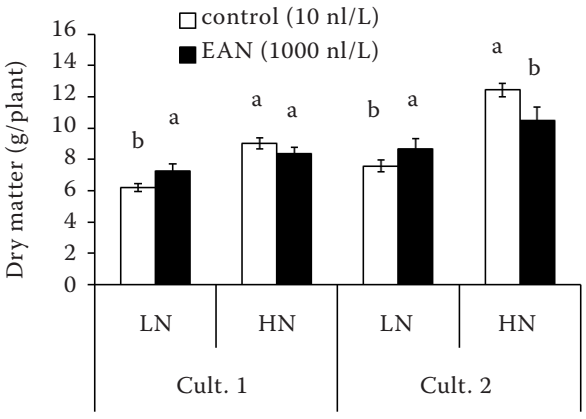

Figure 2. Differential effects of enriched atmospheric NH_3 on dry matter production (g/plant) of SD19 (cult. 1) and NE5 (cult. 2) in the low and high N (LN and HN) medium. Data represent mean of ten replicates (n = 10). At the top of each column, different letters indicate significant differences between enriched atmospheric NH_3 (EAN-1000 nl/L) and control treatment (10 nl/L) with the same cultivar and N level

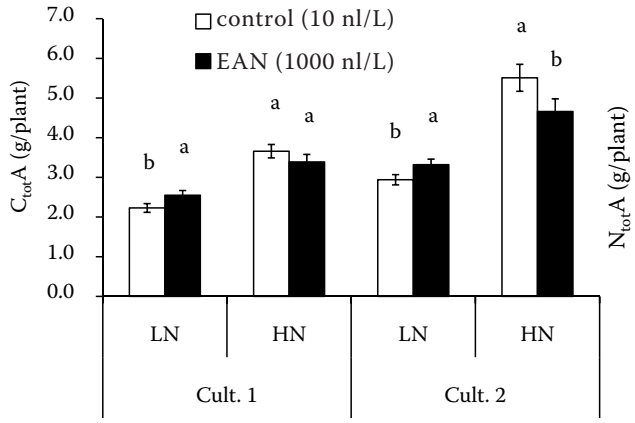

Figure 3. Differential effects of enriched atmospheric NH_3 on total C accumulation ($C_{tot}A$) (g/plant) of SD19 (cult. 1) and NE5 (cult. 2) in the low and high N (LN and HN) medium. Data represent mean of ten replicates (n = 10). At the top of each column, different letters indicate significant differences between enriched atmospheric NH_3 (EAN-1000 nl/L) and control treatment (10 nl/L) with the same cultivar and N level

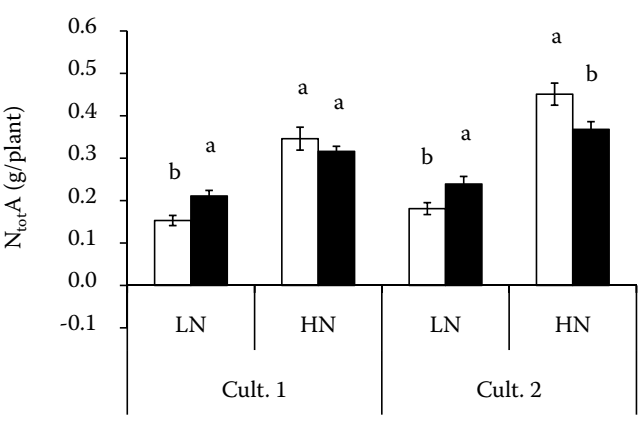

Figure 4. Differential effects of enriched atmospheric NH_3 on total N accumulation ($N_{tot}A$) (g/plant) of SD19 (cult. 1) and NE5 (cult. 2) in the low and high N (LN and HN) medium. Data represent mean of ten replicates (n = 10). At the top of each column, different letters indicate significant differences between enriched atmospheric NH_3 (EAN-1000 nl/L) and control treatment (10 nl/L) with the same cultivar and N level

HN solution, enriched atmospheric NH_3 more decreased $C_{tot}A$ and $N_{tot}A$ of cult. 2 (15% and 18%, respectively) than those of cult. 1 (non-significant) (Figures 2–3). Additionally, the effects of NH_3 level, cultivar, N level and their interactions on $C_{tot}A$ and $N_{tot}A$ were all signifiacnt (Table 1). Such, enhancement of $C_{tot}A$ and $N_{tot}A$ may be significant for plants in natural environments if the NH_3 concentration rises, since N is a limiting factor for plant biomass production in most natural habitats, especially for low NUE cultivars (Fangmeier et al. 1994, Li et al. 2009).

Photosynthesis. Increases of CO_2 assimilation together with net photosynthetic rate (P_n) and apparent quantum yield (AQY) enhancement resulted in lower intercellular CO_2 concentration (C_i) of plants. The modulation of CO_2 concentration in plants might be increase G_s (stomatal conductance),

Table 2. Differential effects of enriched atmospheric NH_3 on photosynthesis parameters of SD19 (cult. 1) and NE5 (cult. 2) in the low and high N medium

Treatment		P_n (μmol CO_2/m^2/s)	C_i (μmol/mol)	G_s (mol/m^2/s)	AQY (mol CO_2/mol)	R_d (μmol CO_2/m^2/s)
Low N (1.67 mmol/L) combined with different NH_3 concentration						
Cult. 1	control	16.18 ± 0.89^b	269.2 ± 10.6^a	0.139 ± 0.016^b	0.078 ± 0.003^b	1.273 ± 0.180^a
	EAN	20.63 ± 1.55^a	195.2 ± 10.3^b	0.193 ± 0.018^a	0.095 ± 0.004^a	1.290 ± 0.220^a
Cult. 2	control	25.02 ± 2.52^b	204.2 ± 8.3^a	0.175 ± 0.014^b	0.093 ± 0.004^b	1.638 ± 0.120^a
	EAN	28.70 ± 2.33^a	163.4 ± 7.9^b	0.225 ± 0.016^a	0.108 ± 0.005^a	1.636 ± 0.180^a
High N (5.00 mmol/L) combined with different NH_3 concentration						
Cult. 1	control	24.02 ± 1.12^a	179.3 ± 8.8^a	0.205 ± 0.014^a	0.099 ± 0.002^a	1.312 ± 0.159^a
	EAN	22.96 ± 1.03^a	188.3 ± 8.7^a	0.183 ± 0.014^a	0.091 ± 0.003^a	1.327 ± 0.156^a
Cult. 2	control	38.24 ± 2.22^a	130.0 ± 7.5^a	0.255 ± 0.018^a	0.123 ± 0.002^a	1.750 ± 0.220^a
	EAN	33.17 ± 2.03^b	153.0 ± 8.3^b	0.212 ± 0.016^b	0.105 ± 0.005^b	1.744 ± 0.250^a

C_i – intercellular CO_2 concentration; control – ambient NH_3 concentration (10 nl/L); G_s – stomatal conductance; AQY – apparent quantum yield; EAN – enriched atmospheric NH_3 concentration (1000 nl/L); P_n – net photosynthetic rate; R_d – dark respiration rate. Data represent mean of ten replicates (n = 10). Mean values followed by different letters within each column indicate significant differences at $P < 0.05$ between enriched atmospheric NH_3 fumigation and control treatment with the same cultivar and N supply

Table 3. *F*-values of the effects of NH_3 level (NH_3), cultivar (Cv), N level (N) and their interactions on photosynthesis parameters

Variation	N	Cv	NH_3	N × Cv	NH_3 × N	Cv × NH_3	N × Cv × NH_3
P_n (μmol $CO_2/m^2/s$)	445.20***	980.25***	2.29	32.44***	116.64***	13.11**	6.02*
C_i (μmol/mol)	10106.2***	10416.3***	2121.1***	49.81***	6664.2***	690.9***	112.6***
G_s (mol/m^2/s)	2036.6***	2908.9***	204.75***	16.29**	3844.7***	84.1***	38.9***
AQY (mol CO_2/mol)	677.60***	1524.60***	12.60**	35.00***	1177.40***	50.40***	22.40***
R_d (μmol $CO_2/m^2/s$)	16.54**	123.50***	0.01	14.43**	0.01	0.01	0.04

C_i – intercellular CO_2 concentration; AQY – apparent quantum yield; G_s – stomatal conductance; P_n – net photosynthetic rate; R_d – dark respiration rate. *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$

which is beneficial for transmition and absorption of atmospheric NH_3 (Fangmeier et al. 1994). Van Hove et al. (1989), Van der Eerden et al. (1992) and Van der Eerden and Pe'rez-Soba (1992) pointed out that increased NH_3 concentration enhanced P_n of *Pinus sylvestris*, poplar trees and Douglas fir, respectively. However, unaffected results in P_n of sunflower (*Helianthus annnus* L.) and *Acacia auriculaeform* were obtained by Berger et al. (1986) and Zhao et al. (2003), respectively. In this study, the authors stated that enriched NH_3 concentration increased P_n, G_s and AQY but decreased C_i in both cultivars in the LN treatment, especially for low NUE cultivar (cult. 1). On the contrary, in the HN treatment, enriched atmospheric NH_3 decreased P_n, G_s, AQY but increased C_i of cult. 2 only. Dark respiration rate (R_d) of both cultivars was not affected by increased atmospheric NH_3 irrespective of N treatment (Table 2). In addition, the signifiacnt effects of NH_3 level, cultivar, N level and their interactions on C_i, G_s and AQY were all obtained. With respect for P_n, non-significant effect of NH_3 level was merely calculated ($P > 0.05$). Nitrogen level, cultivar and their interaction had a significant effect on R_d only (Table 3). Similar result was drawn out by Van Hove et al. (1989) in *Populus euramericana* under 50–100 μg/m^3 NH_3 concentration for 6–8 weeks. However, increase by 76% of R_d in *Populus euramericana* was found under 240 μg/m^3 NH_3 concentration for three months. Thus, the boundary factors for efficient effects of NH_3 fumigation on R_d need to further clarify. The results here show that elevated atmospheric NH_3 concentration played a distinct role in the modulation of these photosynthesis parameters except for R_d of the plants, whose responses were dependent on crop cultivar and N supply in the medium (Fangmeier et al. 1994). These consistencies of photosynthesis physiological parameters change can be useful evaluation index for plant growth under increased atmospheric NH_3 environment. Such atmospheric NH_3 absorption by the plant canopy might offset the N deficiency from root absorption, which showed the stronger use ability of atmospheric NH_3. The possible mechanism might be as following: relative deficiency of N nutrition of plant is beneficial for absorption from atmospheric NH_3 through leaves and synthesis of Rubisco which results in the increase of P_n (Zhao et al. 2003). Under high N medium, excessive NH_3 concentrations in cell possibly restrain Rubisco activity which reduces P_n of plants (Fangmeier et al. 1994).

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